

United States Patent Application

Title

ELECTRON EXPOSURE APPARATUS

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TITELE OF THE INVENTION

ELECTRON EXPOSURE APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of
5 United States Patent Application Serial No. 08/696,089
filed on August 13, 1996, Notice of Allowance to which
was issued on 03/16/98 and the disclosure of which is
incorporated herein by reference.

BACK GROUND OF THE INVENTION

10 Field of the Invention:

The present invention relates to an electron
exposure apparatus employed in a micro-fabrication
technique using a scanning probe microscope.

Description of the Related Art:

15 Nanometer-scale-fabrication technique is
indispensable for fabricating higher integrated
electronic device and higher densificated recording
media. However, the minimum feature size of the
electronic device is limited to about 100nm by the
20 wavelength of light source and a lens material used in
optical lithography. Further, the resolution margin in
a master plate of a recording media is expected to be
smaller in the near future. A nanometer-scale-
fabrication technique using a scanning probe microscope,
25 such as described in, S.C. Minne et al., "Fabrication of
0.1 μ m metal oxide semiconductor field-effect

transistor" Appl. Phys. Lett. 66(6) 6 February 1995 pp.
703-705, or Hyongsok T. Soh et al., "Fabrication of
100nm pMOSFETs with Hybrid AFM/STM Lithography" (1997
SYMPOSIUM ON VLSI TECHNOLOGY), is promising for
5 fabricating nanometer-scale device and recording media.
In general, this method is performed by applying a
voltage between tip and wafer, and the resolution is
atomic level in principle.

Further, a lithography system having a plurality
10 of cantilevers has been also proposed as disclosed in
USP 5,666,190.

SUMMARY OF THE INVENTION

In the case of using the scanning probe microscope
as an electron exposure apparatus, high speed scanning
15 under the simultaneous use of a plurality of tips is
effective as in a micro-fabricated device with
integrated electrostatic actuators, which has been
proposed in USP 5,666,190 or the parent application of
the present application. On the one hand, however, this
20 method needs to control two, i.e., exposure doses and
wafer-to-tip distances with respect to respective tips.
This method also requires not only their drivers but
also a control system for generally controlling all of
them, thereby leading to a complex apparatus.

25 The present invention has taken note of the fact
that the Coulomb forces, which are generated by the
exposure current, is enough large to bend the cantilever

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and to allow the respective tips to contact the wafer surface. Namely, the distance between the tip group and wafer surface is roughly controlled for exposing a current at the start of the electron exposure. In this case, each side of the tip group may be set to have a suitable wafer-to-tip distance. If done in this way, then all the tips can have suitable wafer-to-tip distances within a range of given dispersion incident to the fabrication of the tip group. After once the electron exposure has been started, the wafer-to-tip distances at the each side of the tip group are monitored and controlled to keep the distance determined at the start of the electron exposure.

In other words, in the present invention, electron exposure is carried out while each side of a tip group are kept a suitable wafer-to-tip distance determined at the start of the electron exposure. In doing so, individual tips automatically bend along the surface of the wafer, even if the surface has micro-roughness, by the Coulomb force supplied from exposure current. Thus, wafer-to-tip distance control is not required on each individual tip during electron exposure. Of course, the exposure-current control is required for each individual tip.

Typical ones of various inventions of the present inventions have been shown in brief. However, the various inventions of the present application and specific configurations of these inventions will be

understood from the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention, it is believed that the invention, the objects and features of the invention and further objects, features and advantages thereof will be better understood from the following description taken in connection with the accompanying drawings in which:

Fig. 1 is a block diagram showing the concept of a configuration of an embodiment according to an electron exposure apparatus of the present invention;

Fig. 2A is a perspective view illustrating cantilevers of the electron exposure apparatus shown in Fig. 1 and its holder;

Fig. 2B is a plan view thereof as seen from the back sides of the cantilevers shown in Fig. 2A;

Fig. 3A is a plan view showing other embodiments of the cantilevers of the electron exposure apparatus of the present invention and its holder as seen from the ventral sides of the cantilevers;

Fig. 3B is a side view illustrating the embodiments shown in Fig. 3A;

Fig. 4A is a perspective view depicting embodiments of an integrated tip driver group and a holder thereof capable of being employed in the present

invention;

Fig. 4B is a cross-sectional view showing the structure of each unitary tip driver of the integrated tip driver group shown in Fig. 4A;

5 Fig. 5 is a block diagram illustrating the concept of a configuration of another embodiment of an electron exposure apparatus according to the present invention;

10 Fig. 6 is a diagram showing one example of the relationship between an exposure dose of a current applied from each tip employed in an electron exposure apparatus of the present invention and a line width of a wafer;

15 Fig. 7 is a perspective view depicting embodiments different from the cantilevers and the holder thereof shown in Fig. 2A;

Fig. 8A is a plan view showing modifications of the cantilevers and its holder shown in Fig. 3A as seen from the ventral sides of the cantilevers;

Fig. 8B is a side view depicting the modifications;

20 Fig. 8C is a rear elevation illustrating the modifications;

Fig. 9A is a plan view showing other modifications of the cantilevers and its holder shown in Fig. 3A as seen from the ventral sides of the cantilevers;

25 Fig. 9B is a side view illustrating the modifications shown in Fig. 9A;

Fig. 10A is a plan view depicting further modifications of the cantilevers and its holder shown in

Fig. 3A as seen from the back sides of the cantilevers;

Fig. 10B is a side view showing the modifications shown in Fig. 10A;

Fig. 11A is a plan view showing an example illustrative of parameters of a cantilever, for describing a displacement thereof due to the Coulomb force;

Fig. 11B is a side view showing the example illustrative of the parameters shown in Fig. 11A;

Fig. 12A is a plan view depicting an example illustrative of other parameters of a cantilever, for describing a displacement thereof due to the Coulomb force; and

Fig. 12B is a side view illustrating the example illustrative of the parameters shown in Fig. 12A.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[EMBODIMENT I]

In the present embodiment, an embodiment of an electron exposure apparatus wherein a plate wafer is moved or displaced in a plane direction thereof to draw an image or perform electron exposure, will be described with reference to Figs. 1 and 2.

Fig. 1 is a block diagram showing the concept of a configuration of a first embodiment of an electron exposure apparatus of the present invention. A micro-fabrication image-drawing or electron-exposure head 1 comprises a micro-fabrication electron exposure unit 4

and a slop or inclination corrector 5. The micro-fabrication electron exposure unit 4 comprises conductive springs 22a, 22b, 22c and 22d respectively used as cantilevers and conductive probes or tips 21a, 21b, 21c and 21d respectively connected to the springs and a holder 24 for collectively holding these. The holder 24 is coupled to the slope corrector 5 through piezo elements 25 and 26. The slope corrector 5 has the opposite side of a surface coupled to the piezo elements 25 and 26, which is held by an unillustrated electron exposure apparatus body. Further, the slope corrector 5 supplies a voltage to each of the piezo elements 25 and 26 in response to an inclination correction signal supplied from a drive and exposure controller 13 to be described later to thereby correct the inclination of the holder 24 so that a line connecting the tips 21a and 21d at both ends to each other becomes parallel to the surface of a resist layer 11 of a wafer 8 to be subjected to electron exposure. A voltage application part 7 controls voltages to be applied to the tips 21a through 21d in response to a control signal supplied from the drive and exposure controller 13. In this case, the voltage application part 7 controls the voltages to be applied to the tips 21a through 21d so that they become suitable voltages respectively where the inclination of the holder 24 is corrected using the tips 21a and 21d provided at both ends and electron exposure is performed by using the tips 21b and 21c. A current

detector 6 detects each of currents applied to the resist layer 11 through the tips and feeds back its detected output to the drive and exposure controller 13. Upon execution of the inclination correction, the drive and exposure controller 13 supplies a suitable voltage to each of the tips 21a and 21d and controls voltages to be applied to the piezo elements 25 and 26 so that their currents become equal to one another. Upon execution of the electron exposure, the drive and exposure controller 13 controls the voltage to be applied to each of the tips 21b and 21c, i.e., the voltage application part 7 so that it becomes a current corresponding to a control signal associated with an electron-exposure pattern supplied from a pattern input part 60. Now consider a current to flow through the resist layer 11. When the resist layer 11 is high in insulation, the current results in a field emission current, whereas when the resist layer 11 is conductive, it results in a so-called current. In the present invention, this will be defined as "current" without drawing a distinction between the two.

The drive and exposure controller 13 supplies a transfer or movement signal to a moving or transfer part 12 in response to the control signal supplied from the pattern input part 60. The transfer part 12 has one surface held by the unillustrated electron exposure apparatus body and a surface different from one surface thereof, which is provided with drive mechanisms 16, 17

and 18 for displacing a transfer stage 15 in X, Y and Z directions according to the transfer signal. Although the drive mechanisms have been shown by the blocks 16, 17 and 18 in a sense that they are triaxially driven in the X, Y and Z directions, those having configurations used in the form of arbitrary mechanisms such as a Pattern Aligner, etc. may be adopted. A displacement of the transfer stage 15 is measured by a high-resolution measuring device such as a laser interferometer or the like. The result of measurement thereof is fed back to the drive and exposure controller 13 where it is controlled precisely. The wafer 8 is mounted on the transfer stage 15.

Prior to the electron exposure, the transfer part 12 moves the transfer stage 15 in response to an approach signal supplied from the drive and exposure controller 13 until the tips 21a through 21d are placed in their corresponding predetermined positions by the Z-axis drive mechanism 18 with respect to the surface of the resist layer 11 of the wafer 8 to be subjected to the electron exposure, thereby allowing the resist layer 11 of the wafer 8 to approach the tips 21a through 21d. At this time, suitable voltages are applied to the tips 21a through 21d respectively. When a current detected from any of the tips has reached a predetermined value, its approach is stopped.

After the inclination correction has been performed, the transfer part 12 moves the transfer stage

15 on an X-Y surface through the X-axis drive mechanism
16 and the Y-axis drive mechanism 17 so that a pattern
is drawn on the resist layer 11 of the wafer 8. In
order that while the pattern is being drawn thereon, the
5 magnitude of a current is monitored using the tips 21a
and 21d located at both ends to thereby maintain the
distance between the resist layer 11 and each tip as a
suitable value, the transfer part 12 is controlled by
the drive and exposure controller 13 so as to continue
10 position control in a Z-axis direction.

The wafer 8 consists of a glass-made substrate 9,
a conductive layer 10 formed by evaporating chromium
onto the substrate 9 over a range of 20nm to 100nm in
thickness, and a resist layer 11 (corresponding to a
15 layer coated with a Negative-type resist (RD2100N;
product of Hitachi Chemical Co., Ltd.) corresponding to,
for example, an Azide/phenolic resin resist) having a
thickness of about 100nm. A resist employed in the
resist layer 11 may be a resist composed of a mixture of
20 a novolak resin and a photo-active compound, a
chemically amplified resist or polymethyl methacrylate.
The substrate 9 may use an arbitrary material to be
processed, such as silicon, doped silicon or the like.
When the doped silicon is used for the substrate 9, the
25 conductive layer 10 may be omitted due to the
conductivity of the substrate 9 itself. The conductive
layer 10 is electrically grounded so that the current
flows through the resist layer 11 according to the

voltage applied to each tip. When the conductive substrate 9 is used, it may be directly grounded.

Fig. 2A is a perspective view showing the cantilevers and the holder therefor of the electron exposure apparatus shown in Fig. 1. Fig. 2B is a plan view showing the cantilevers as seen from the back sides thereof. The tips 21a through 21d are provided at the leading ends of the springs 22a through 22d which serve as the cantilevers, respectively. Further, conductive films 23a through 23d are formed on one surfaces of the springs 22a through 22d respectively. These conductive films are electrically connected to the voltage application part 7 and the current detector 6 through unillustrated connectors. The tips 21a through 21d and the springs 22a through 22d are held by the holder 24 but integrally formed by a silicon single crystal using a micro-fabrication technique, for example. These may be silicon oxide or silicon nitride. The piezo elements 25 and 26 for correcting the slope of the holder 24 and performing the above transfer for approach are provided on a cantilever-free surface of the holder 24.

A radius of curvature of the leading end of each tip 21, a spring constant of each spring 22 and a resonant frequency may suitably be in the ranges of 10nm to 100nm, 0.05N/m to 5N/m and 10kHz to 50kHz respectively. Further detailed data about these parameters will be described later.

It can be said that although the leading positions

of the respective tips 21a through 21d with respect to the wafer 8 depend on working accuracy, they can be kept in a dispersion range of less than or equal to 50nm and substantially placed on the same line. Each conductive
5 film 23 is a titanium thin film ranging from 10nm to 50nm in thickness, which is formed by evaporation. In addition to titanium, tungsten, molybdenum, titanium carbide, tungsten carbide or molybdenum carbide may be used as the conductive film.

10 An electron exposure procedure using the electron exposure apparatus shown in Figs. 1 and 2 will be collectively explained. The electron exposure takes a procedure for approaching each tip by the wafer 8 as a first stage, correcting the slope of each tip as a
15 second stage and performing electron exposure as a final stage.

As mentioned previously, the wafer 8 is first mounted on the transfer stage 12 and thereafter a suitable voltage is applied to each of the tips 21a
20 through 21d by the voltage application part 7. These currents resultant from the voltage are detected by the current detector 6. Further, the transfer stage 12 is moved in the Z-axis direction under the control of the drive and exposure controller 13 until the current
25 flowing through any of the tips reaches a predetermined value to thereby allow the wafer 8 to approach each tip. At this time, the voltage application part 7 varies a voltage V applied between each of the tips 21a and 21d

and the wafer 8. A current I that flows at this time,
is detected by the current detector 6. Thereafter, the
capacitance between the wafer 8 and each tip may be
calculated from $I/(dV/dt)$ to estimate the distance
5 between each tip and the wafer 8.

Next, the drive and exposure controller 13
supplies a signal to the slope corrector 5 so that the
difference in current between both tips 21a and 21d
provided at both ends is brought to nothing, thereby
10 controlling the piezo elements 25 and 26, whereby an
inclination formed between a line for connecting these
tips to each other and the plane of the wafer 8 is
controlled so as to be eliminated. Alternatively, it
may be practiced to calculate the capacitance, estimate
15 the slope from the distance, and supply a signal from
the drive and exposure controller 13 to the slope
corrector 5 so as to control the piezo elements 25 and
26, thereby correct the slope.

The distance between each of the tips 21a through
20 21d and the wafer 8 becomes less than or equal to a
predetermined value. After the completion of the slope
correction, the electron exposure apparatus proceeds to
an electron exposure process. A set value of the
distance between each of the tips 21a through 21d and
25 the wafer 8 may suitably range from 10nm to 1 μ m.

A description will next be made of the electron
exposure. The electron exposure is performed by
applying a voltage corresponding to an electron-exposure

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pattern supplied from the pattern input part 60 between
each of the tips 21c and 21d and the conductive layer 10
by the voltage application part 7 under the control of
the drive and exposure controller 13 while moving the
5 wafer 8 on the transfer stage 12 along the X-Y surface.
Thus, currents flow in the resist layer 11 directly
below the tips 21c and 21d and thereby resist molecules
react with each other to form a latent image within the
resist layer 11.

10 The voltage therebetween applied from the voltage
application part 7 is varied by the drive and exposure
controller 13 so that the currents detected by the
current detector 6 or currents obtained by correcting
currents charged and discharged through capacities
15 between the tips and the substrate become constant as
exposure doses (exposure currents). This can be
controlled in various forms. Specific examples will be
enumerated as follows:

(1) when a current I is controlled, a voltage
20 value given by an expression 1 is outputted:

$$V(t) = G_i \int_0^t (I_s - I(t)) dt \quad (1)$$

where G_i indicates feedback gain and I_s indicates a set
current.

(2) when power $P = IV$ is controlled, a voltage
25 value represented by an expression 2 is outputted:

$$V(t) = G_p \int_0^t (P_s - I(t)V(t)) dt \quad (2)$$

where G_p indicates feedback gain and P_s indicates set power.

(3) When capacitances C , which exist between the tips 21a through 21d and springs 22a through 22d and the substrate 9 are taken into consideration, a charge and discharge current given by an expression 3 flows as a voltage V varies:

$$I_c(t) = C \frac{dV}{dt} \quad (3)$$

the output voltage at current control, which is given by the expression 1, is rewritten as the following expression in consideration of the expression 3:

$$V(t) = G_i \int_0^t \left\{ I_s - \left(I(t) - C \frac{dV}{dt} \right) \right\} dt \quad (4)$$

Further, the output voltage at power control, which is given by the expression 2, is rewritten as follows:

$$V(t) = G_p \int_0^t \left\{ P_s - \left(I(t) - C \frac{dV}{dt} \right) V(t) \right\} dt \quad (5)$$

(4) Further, a feedback control system constructed by the current detector 6 and the drive and exposure controller 13 has a time constant τ and thereby removes a high-frequency component. This feedback control system serves as a filter even with respect to the charge and discharge current I_c . In order to accurately eliminate the influence of I_c , the above expression (4) is rewritten in the following manner in consideration of the time constant τ :

$$V(t) = G_i \int_0^t \left\{ I_s - \left(I(t) - \frac{C}{\tau} \int_0^t \frac{dV}{dt} e^{\frac{t'-t}{\tau}} dt' \right) \right\} dt \quad (6)$$

Thus, the above expression (5) is given as follows:

$$V(t) = G_p \int_0^t \left\{ P_s - \left(I(t) - \frac{C}{\tau} \int_0^t \frac{dV}{dt} e^{\frac{t'-t}{\tau}} dt' \right) V(t) \right\} dt \quad (7)$$

In the present embodiment, the wafer 8 coated with
 5 the resist RD2100N having the thickness of 100nm is
 moved at 0.1mm/s so that the voltage applied between
 each of the tips 21c and 21d and the conductive layer 10
 is set to the neighborhood of - 85V and the current is
 set to be 100pA, i.e., the exposure dose is set to be
 10 10nC/cm.

During a period in which the latent image is being
 formed within the resist layer 11, the tips 21b and 21c
 undergo the Coulomb force, which acts between each of
 the tips 21b and 21c and the conductive layer 10 by the
 15 voltage applied to create the latent image. Due to the
 Coulomb force, the respective springs 22b and 22c are
 bent or deformed and the respective tips are held in
 contact with the resist layer 11. There are also
 portions in which no latent images are formed according
 20 to patterns to be created. Since the portions do not
 need the currents, it is unnecessary to apply the
 voltage to the corresponding tips at these positions.
 However, since the Coulomb force, which has acted on the
 tips, is brought to nothing when the voltage is set to
 25 0V, no respective springs 22b and 22c are deformed and
 thereby spaced away from the surface of the resist layer

11. In the case, the Coulomb force abruptly acts on the tips when the voltage is applied thereto at the position to form the latent image again, so that the respective springs 22b and 22c are suddenly deformed. Therefore, there is a high possibility that the tips will hit against the resist layer 11 heavily to thereby break. Thus, when the latent-image creation-free portions are subjected to electron exposure, it is better to control the voltage so that such a small current as not to form the latent image flows. In the present embodiment, the current becomes less than or equal to 1pA when the voltage to be applied is set to - 70V or less, and hence no latent image was not formed. On the other hand, the current used for position monitoring by the tips located at both ends is naturally performed to this extent or less. However, the impressed voltage may preferably be set to such a voltage as to merely supply a smaller current in such a manner that the respective springs 22a and 22d are not deformed by the Coulomb force wherever possible.

A brief description on development of the latent image drawn by the present invention is as follows:

The latent image is developed by being immersed in a tetramethylammonium hydroxide solution of 0.83% for one minute. As a result, when a negative-type resist is used for the resist layer 11, only a resist with a latent image formed thereon is left behind without its dissolution, so that a convex type line resist pattern

having a line width of 100nm can be created. When a positive-type resist is used for the resist layer 11, only a resist with a latent image formed thereon is dissolved to thereby create a concave type line resist pattern having a line width of 100nm. Fig. 6 shows the relationship between a pattern width and an exposure dose employed in the embodiment of the present invention. The same drawing shows the case in which since the pattern width depends on the exposure dose, an arbitrary pattern width of 100nm or more can be formed by adjusting the exposure dose.

In the present invention, the electron exposure takes a procedure for approaching each tip by the wafer 8 as a first stage, correcting the slope of each tip as a second stage and performing electron exposure as a final stage. Tips at ends, of many tips are used for positioning and monitoring of positions being under electron exposure, and other tips are used for electron exposure, whereby tips used for electron exposure may simply perform current control alone. Further, the present invention could provide a useful approach or method in that an attention has been focused on the fact that the electron exposure could be achieved by the current control alone without strict position control due to the deformation of each tip by the Coulomb force upon formation of the latent image. In the description of the above embodiment, the number of tips is less because of only four. However, the more the number of

the tips increases, the more the merit of the present invention becomes great. Incidentally, the aforementioned embodiment shows the case in which the approach of each tip to the wafer 8 is made by moving the wafer 8 in the Z-axis direction. However, the piezo elements 25 and 26 on the holder 24 holding the tips thereon may be used for this approach.

[EMBODIMENT II]

Fig. 3A is a plan view showing other embodiments of the cantilevers of the electron exposure apparatus of the present invention and its holder as seen from the back sides of the cantilevers. Fig. 3B is a side view thereof. As is understood in contrast with Figs. 2A and 2B, a tip unit 30 having a number of springs 31a, 31b, ..., 31k, ..., 31n, and 32a, ... 32m, ... 3jm is shown as an illustrative example. These springs are respectively held within holders 34a, 34b, 34c and 34d and their holders are held by a common holder 35. While conductive lines for respective tips are typically designated at numerals 33, they are caused to lead through unillustrated connectors to provide necessary connections. As shown in Fig. 3B, piezo elements 36 through 36c corresponding to the piezo elements 25 and 26 shown in Fig. 2A are provided on the back of the common holder 35. The piezo element 36a is not seen from the drawing. The piezo elements 36a and 36b are used to control a slope or inclination in an X direction shown in the drawing using the tips 31a and 31n. The

piezo elements 36b and 36c are used to control an inclination in a Y direction shown in the drawing using the tips 31n and 3jm.

[EMBODIMENT III]

5 Fig. 4A is a perspective view showing embodiments of an integrated tip driver group and a holder thereof both capable of being employed in the present invention. Fig. 4B is a cross-sectional view showing the structure of each unitary tip driver shown in Fig. 4A.

10 Fig. 4A is a conceptual diagram showing the structure of an embodiment in which a number of tip drivers 420 shown in Fig. 4B are two-dimensionally in X and Y direction and held by a coarse mechanism 410 to thereby allow control on the positions of the tips. The
15 number of tip drivers 420 corresponding to the respective tips and springs shown in Figs. 3A and 3B are two-dimensionally placed in the X and Y directions. The structure in which a group of the tip drivers 420 is held by the coarse mechanism 410 corresponding to the
20 common holder 35 and piezo elements 36a through 36c shown in Figs. 3A and 3B to thereby allow control on the positions of the tips, is shown in the drawing.

If done in this way, then the coarse mechanism 410 can perform XY two-dimensional driving for electron
25 exposure as well as to execute an approach and a slope correction. It is of course needless to say that their functions may be divided into parts so as to bear their burdens as in the aforementioned embodiment.

The structure of the coarse mechanism 410 employed in the present embodiment will not be described in detail. However, if the structure thereof is devised by micro-fabrication in a manner similar to the fabrication of the tip drivers 420 shown in Fig. 4B and the combination of it with the piezo elements is devised, it can be then easily fabricated. Conversely, the simple holder and piezo elements shown in Fig. 2A may be utilized in combination.

An example of the tip driver 420 will be explained below with reference to Fig. 4B. Fig. 4B is a block diagram showing one example of the structure of the tip driver 420. The present embodiment is equivalent to one in which a first integrated electrostatic actuator 2100 and a second integrated electrostatic actuator 2500 are cascade-connected. Namely, a fixed electrode 270 of the second actuator 2500 is electrically connected to a movable electrode 210 of the first actuator 2100. A tip 220 is mounted to a drawn or extended leading end of the movable electrode 250 of the second actuator 2500.

Further, the first integrated electrostatic actuator employed in the present embodiment is one actuator and can be driven in X and Y directions. Thus, movements in the X and Y directions and a movement in a Z direction are controlled by the first actuator 2100 and the second actuator 2500 respectively.

Fixed electrodes 211 of the actuator 2100 are provided at the leading end of a base 230. A spring 240

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comprised of plate springs 241 and connecting portions 242 for respectively coupling the plate springs 241 to each other is provided at the leading end of the base 230 in the same manner as described above. The movable electrode 210 of the actuator 2100 is coupled to its corresponding connecting portion 242 of the spring 240. The other ends of the fixed electrodes 211 of the actuator 2100 are coupled to base end portions 232. A spring 240' made up of plate springs 241' and connecting portions 242' for coupling the plate springs 241' to each other is provided at the base end portions 232. The movable electrode 210 of the actuator 2100 is coupled to a connecting portion of the spring 240' and a Z-drive shaft 270 is coupled to the connecting portion of the spring 240'. Since driving forces, which act between the fixed electrodes 211 and the movable electrode 210 of the actuator 2100, bend the springs 240 and 240' respectively, the Z-drive shaft 270 takes positions in an X direction (parallel to the sheet and in the left and right directions) and a Y direction (normal to the sheet) corresponding to the driving forces of the actuator 2100.

The integrated electrostatic actuator 2500 is provided at the leading end of the Z-drive shaft 270 in the form of the Z-drive shaft 270 as the aforementioned base 230. Namely, fixed electrodes 251 supported by a frame portion 270' formed integrally with the Z-drive shaft 270 are formed. Similarly, a spring 260 comprised

of plate springs 261 with the frame portion 270' as a fixed portion and connecting portions 262 for coupling the plate springs 261 to each other, and a spring 260' comprised of plate springs 261' and connecting portions 262' for coupling the plate springs 261' to each other, are formed. A tip supporter 280 whose leading end is provided with the tip 220, is coupled to a connecting portion 263 of the spring 260 and a connecting portion 263' of the spring 260'. Further, the movable electrode 250 of the actuator 2500 is coupled to the tip supporter 280. Since driving forces, which act between the fixed electrodes 251 and the movable electrode 250 of the actuator 2500, flexes the springs 260 and 260' respectively, the tip supporter 280 assumes a position in an Z direction (parallel to the sheet and in upward and downward direction). In the present embodiment, the Z-drive shaft 270 performs control in the X and Y directions through the actuator 2100 and the tip performs control in the Z direction in this condition.

Although descriptions about wiring or interconnections to the respective electrodes, interconnections for a voltage to be applied to each tip and the need or not for insulation have been omitted in the illustrated embodiment to simplify illustrations in the drawing, they can be implemented by arbitrary configurations as needed. Therefore, a further description will be omitted.

A plurality of the structures each illustrated in

the embodiment shown in Fig. 4B are one-dimensionally placed in parallel so as to be brought into integration by a semiconductor micro-fabrication technique with one substrate as a base. Further, the base 230 and the base end portions 232 may be directly mounted on one substrate used as the base and other portions are processed by the semiconductor micro-fabrication technique, whereby integrated tip drivers having integrated electrostatic actuators can be configured in form away from the substrate. Thus, the integrated tip drivers one-dimensionally placed on one chip in parallel can be extremely easily constructed.

Two-dimensionally disposed integrated tip drivers can be also easily formed by stacking the structures of the integrated tip drivers one-dimensionally placed in parallel on one chip, according to the present embodiment on one another in plural form.

In the present invention, since the number of tip drivers 420 are enough if the entire approach, the slope correction and the position control being under electron exposure are carried out, it is essentially unnecessary to control the positions of the individual tips 220 of many tip drivers. However, this ability is useful if a correction to partial electron exposure or the like is taken into consideration.

[EMBODIMENT IV]

An embodiment used as an electron exposure apparatus for rotating a wafer to make electron exposure

will next be described with reference to Fig. 5. The present embodiment essentially remains unchanged as compared with the electron exposure apparatus according to the embodiment shown in Fig. 1. However, the present
5 embodiment is equivalent to one in which a wafer 8 is rotated and a micro-fabrication electron exposure head 1 is placed so as to be put to one side of the wafer 8. Elements of structure used in common in both embodiments are identified by the same reference numerals. The
10 transfer part 12, the transfer stage 15 and the drive mechanisms 16, 17 and 18 to be moved in the X, Y and Z directions, which are employed in the embodiment shown in Fig. 1, are replaced by a rotatable driving part 61, a rotatable stage 65 and a rotatable shaft 66
15 respectively. A drive and exposure controller 13 supplies a rotation signal to the rotatable driving part 61 in response to a control signal supplied from a pattern input part 60. This rotation signal allows the rotatable stage 65 to be rotated through the rotatable
20 shaft 66 and information about this rotation is fed back to the drive and exposure controller 13, where position control is performed precisely.

Although an approach operation is done prior to the electron exposure even in the present embodiment,
25 this operation allows the rotatable shaft 66 to be shift (Z-axis driven) upwardly according to a signal supplied to the rotatable driving part 61 from the drive and exposure controller 13. When the rotatable stage 65 is

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moved until tips 21a through 21d take predetermined positions with respect to the surface of a resist layer 11 of the wafer 8 to be subjected to electron exposure, their approaches are brought to completion. Thereafter, a slope correction is carried out and consecutively the rotatable stage 65 is rotated to draw a pattern on the resist layer 11 of the wafer 8. The rotatable driving part 61 is controlled by the drive and exposure controller 13 to continue position control in an Z-axis direction in such a way as to monitor the magnitudes of currents using the tips 21a and 21d located at both ends and thereby maintain the distance between the resist layer 11 and each tip as a suitable value while the pattern is being drawn. Further, the present embodiment is considered to frequently need the operation of correcting a slope resultant from rotation by a corrector 5 even during the electron exposure as compared with the embodiment shown in Fig. 1. However, the operation can be executed without any hindrance owing to the monitoring of positions by the tips located at both ends.

Since the micro-fabrication electron exposure head 1 is relatively small as compared with the wafer 8 in the present embodiment, a complete round-shaped resist pattern usable in a recording track of an optical disk, for example can be formed if the wafer 8 is developed after having been rotated 360° by the wafer rotatable stage 65. Further, if the wafer 8 is developed after

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having been rotated 360° by the wafer rotatable stage 65 while the micro-fabrication electron exposure head 1 is being moved in the direction of the center of rotation thereof from side to side with a certain point thereof as the center while a constant exposure dose is being radiated continuously, then a waveformed resist pattern can be formed in circular form. Alternatively, if the wafer 8 is developed after the micro-fabrication electron exposure head 1 has been fixed and the wafer 8 has been rotated 360° by the wafter rotatable stage 65 while switching is made between a latent-image formable exposure dose and a latent-image unformable exposure dose, then a dot pattern usable for data information and address information in the optical disk can be formed in circular form. If this operation is continuously performed so as to draw patterns over the entire area of the wafer 8, then the patterns can be drawn over the entire area thereof in twenty hours under the condition that the tips are arranged at 0.1mm pitches, track pitches are defined as 100nm and the rotational speed is at 50rpm.

An original plate for the optical disk can be created by combining the methods shown in the above. Further, if a concave type dot resist pattern is formed over the entire surface of the disk and a magnetic material such as an iron, cobalt, nickel, iron-cobalt alloy, a cobalt-nickel alloy, an iron-nickel alloy or the like is buried in the dot pattern by electric

plating with a conductive layer 10 as an electrode, then an ultrahigh-density magnetic recording medium with magnetic dots as isolated recording bits can be created.

[EMBODIMENT V]

5 Next, Fig. 7 is a perspective view showing different embodiments of the cantilevers and their holder shown in Fig. 2A.

10 The present embodiment illustrates one, as an example, in which displacements in cantilevers 22a and 22d located at both ends are detected by an optical level deflection sensor type atomic force microscope. Reference numerals 83 and 81 indicate light sources and reference numerals 84 and 82 indicate photo-detectors. Since the atomic force microscope does not need to allow
15 currents to flow between tips 21a and 21d and a wafer 8, it is unnecessary to apply a voltage to each tip 21. Thus, springs are not deformed by experiencing the Coulomb force resultant from the voltage applied to each of the tips 21a and 21d. Therefore, when the atomic
20 force microscope is used to monitor positions by the tips located at both ends, stable position control and slope control can be achieved.

[EMBODIMENT VI]

25 Fig. 8A is a plan view showing modifications of the cantilevers and their holder shown in Fig. 3A as seen from the back sides of the cantilevers. Fig. 8A is a side view thereof. Fig. 8C is a rear elevation thereof.

As is clearly understood in the present embodiment from the contrasts between Fig. 3A and Fig. 8A and between Fig. 3B and Fig. 8B, holders 34a through 34d are divided into two: 34a', 34a' to 34d', 34d' every rows of cantilevers. Further, the cantilevers are inclined toward their corresponding holders and set identical to one another in direction. Moreover, the present embodiment shows one in which displacements in cantilevers 31a, 31n and 31m at ends are detected by an optical lever deflection sensor type atomic force microscope in a manner similar to the embodiment shown in Fig. 7. Reference numerals 91, 93 and 95 indicate light sources and reference numerals 92, 94 and 96 indicate photo-detectors, respectively. The present embodiment brings about an advantageous effect in that since the cantilevers are set to have the same slopes and directions, springs of cantilevers effectively act on irregularities or projections and depressions of the surface of a resist 11 upon movement of a wafer 8, whereby the possibility that tips will be damaged, can be reduced. Further, since the displacements in the cantilevers are detected by the atomic force microscope, an advantageous effect can be also brought about in that stable position and slope control can be achieved in a manner similar to the previous embodiment. In the present embodiment, as is apparent by reference to Fig. 8C, some of a holder 35 must be cut so as to cause light to pass therethrough in order to transmit light of the

atomic force microscope for detecting a displacement in the cantilever 3jm.

[EMBODIMENT VII]

Fig. 9A is a plan view showing other modified
5 embodiments of the cantilevers and their holder shown in Fig. 3A as seen from the ventral sides of the cantilevers. Fig. 9B is a side view thereof.

As is clearly understood from the contrasts
between Fig. 8A and Fig. 9A and between Fig. 8A and Fig.
10 9A, the present embodiment shows one, as an example, in which as an alternative to the detection of the displacements in the cantilevers 31a, 31n and 3jm at the ends by the atomic force microscope, the approach of the tip unit 30 to the wafer 8 and the monitoring of their
15 positions are carried out by providing electrodes 41, 42 and 43 at three points of the surface of a holder 35 on the cantilever side and detecting capacitances between the electrodes and a conductor portion of the wafer.

In the present embodiment, when the wafer is set
20 to a transfer stage 15, no capacitances cannot be substantially detected. However, when the approach to the wafer 8 proceeds and the tip unit 30 approaches the wafer 8 to some extent, the capacitances can be detected. The approach of the tip unit 30 to the wafer 8 can be
25 completed using this. Further, even the monitoring of their positions during electron exposure can be performed using it.

[EMBODIMENT VIII]

Fig. 10A is a plan view showing further
embodiments illustrative of modifications of the
cantilevers and their holder shown in Fig. 3A as seen
from the ventral sides of the cantilevers. Fig. 10B is
5 a side view thereof.

As is clearly understood from the contrasts
between Fig. 9A and Fig. 10A and between Fig. 9B and Fig.
10B, the present embodiment is one in which the
relationship in position between a tip unit 30 and a
10 wafer 8 is directly held by sliders 51, 52, 53 and 54
interposed therebetween. Weak spring devices 55, 56, 57
and 58 (57 and 58 not shown in the drawing) are provided
at the four corners of the back of a holder 35 so that
these sliders are kept in contact with the wafer 8 by a
15 weak force.

In the present embodiment, the wafer 8 is set to a
transfer stage 15 and thereafter the holder 35 is
pressed against the wafer 8 by a weak force at an
approach stage. Afterwards, if this state is kept as it
20 is, it is then unnecessary to perform position control
being under electron exposure in particular.

[Examples of parameters for cantilevers]

Fig. 11A is a plan view showing one example
illustrative of parameters for each cantilever, for
25 describing a displacement in cantilever by the Coulomb
force. Fig. 11B is a side view thereof. The cantilever
illustrated in this example has a width of W , a length
of L and a thickness of t . Further, the length of a tip

ranges from about 10 to 15 μ m. In this example, the Coulomb force was roughly calculated by a parallel plate capacitor formed between the conductive layer 10 and each cantilever 22 shown in Fig. 1.

5 A force F, which acts between electrode plates of the parallel plate capacitor, is first given by the following equation. In the equation, ϵ_0 indicates a dielectric constant of a dielectric that exists between the electrode plates, S indicates the area of each
10 electrode plate, V indicates a voltage applied between the electrode plates, and d indicates the distance between the electrode plates.

$$F = \epsilon_0 \frac{SV^2}{2d^2}$$

The three samples of A through C different in
15 constant from each other are now prepared as the cantilevers. Their parameters are respectively as follows:

Sample	Width W μ m	Length L μ m	Thickness t μ m	Spring constant CN/m
A	50	450	2.0	0.1
B	60	450	4.0	2.0
C	30	225	5.0	20.0

Assuming now that the area of electrode plate S is
20 same as the area of the cantilever holding the tip, the result of calculation made to the Coulomb force between the cantilever and wafer face is given in Table shown below.

Area of cantilever S	Distance between electrode plates d	Voltage between electrode plates V	Coulomb force F
$50 \mu\text{m} \times 450 \mu\text{m}$	$16 \mu\text{m}$	40V	630 nN

The result of calculation made to the amounts of deformation or bending of the above samples by now noting an example in which the Coulomb force is 630nN, is given in Table shown below.

Sample	Amount of bending (nm)
A	6300
B	315
C	32

10

As is understood even from the example, such a large force and deformation or bending occur even when the voltage is 40V. Thus, when -80V is applied upon the aforementioned electron exposure, each cantilever greatly deforms or bends and hence control on the position of each cantilever for electron exposure does not make sense. Conversely, the cantilevers stably follow the non-uniformity of the thickness of the resist layer 11 due to this deformation. This is an important point of view of the present invention to be noted.

Next, Fig. 12A is a plan view showing another example illustrative of further parameters of a cantilever, for describing a displacement in cantilever by the Coulomb force. Fig. 12B is a side view thereof.

The cantilever shown in this example is a two-point supported beam. Two examples having $4 \mu\text{m}$ defined as widths W of their leading ends, $0.4 \mu\text{m}$ defined as their thicknesses t , $200 \mu\text{m}$ and $100 \mu\text{m}$ defined as their lengths L , 0.02 and 0.09 defined as spring constants and about $6 \mu\text{m}$ defined as tip lengths were calculated. The two examples are identical to each other in leading-end's structure and configuration and different from one another in length L alone. When the area of a tip with respect to the surface of each of the cantilevers in the examples is defined as $3700 \mu\text{m}^2$, the distance d between electrode plates is defined as $6 \mu\text{m}$ and the applied voltage is defined as 40v , the Coulomb force was 730nN . If the force corresponding to this extent is given, then the cantilever will cause deformations of about 37000nm and 8100nm in a manner similar to the cantilever shown in Fig. 11. Thus, even this type of cantilever can take full advantage of deformation.

Although the tip drivers shown in Figs. 4A and 4B have no cantilevers and do not construct a parallel plate capacitor as in these examples, the Coulomb force that acts on each tip, can be fully utilized because springs 261 and 261' are extremely soft.

According to the present invention, as has been described above, since one control on each tip with respect to the wafer may be performed only at each side of the tip group and only control on the currents may be carried out at other tips, an electron exposure

apparatus capable of performing electron exposure at high speed can be easily fabricated.

Since it is unnecessary to strictly perform the approach and the slope control, such structures as shown in Figs. 9 and 10 may be used as the simplest structure or may be one, although not shown in the drawing, of a type wherein electrodes are placed on the backs of cantilevers and displacements in cantilevers are detected from changes in capacitance between the two.

While the present invention has been described with reference to the illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications of the illustrative embodiments, as well as other embodiments of the invention, will be apparent to those skilled in the art on reference to this description. It is therefore contemplated that the appended claims will cover any such modifications or embodiments as fall within the true scope of the invention.